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# DESIGN AND INITIAL OPERATION OF A 3-DEGREE OF FREEDOM MAGNUS ROTOR IN A MAGNETIC BALANCE SYSTEM

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BY
JAMES B. COFFIN
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JANUARY 1973





PICATINNY ARSENAL
DOVER, NEW JERSEY

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13. ABSTRACT

Progress is reported on an experimental program to determine the Magnus forces on the center of gravity and the rotational startup response of a self-spinning rotor in a subsonic air stream. Development of a new type of model for the magnetic balance system was required in order to provide rotational freedom about all three axes. The design, construction and initial testing of this model at low subsonic speeds are discussed. The results indicate that models with three degrees of rotational freedom can be suspended with the magnetic balance system and tested in a subsonic air stream. Because of the force limits of the present balance system, the maximum operating dynamic pressure for this model is low.



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Picatinny Arsenal
Dover, New Jersey

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By

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## FOREWORD

This work was performed at the Aerophysics Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139. The work was sponsored by the U. S. Army Munitions Command, Picatinny Arsenal, Dover, New Jersey 07801 under Contract DAAA21-72-C-0254. This contract was monitored by Mr. Alfred Loeb, Chief, Aeroballistics Branch, Picatinny Arsenal, Dover, New Jersey. Overall supervision of this study was provided by Professor Eugene E. Covert, of the M. I. T. Aerophysics Laboratory, in the capacity of Principal Investigator. This report covers work performed during the period February 7, 1972 to August 31, 1972.

The authors would like to thank the NASA Langley Research Center for the use of the magnetic balance equipment.

ABSTRACT

Progress is reported on an experimental program to determine the Magnus forces on the center of gravity and the rotational startup response of a self-spinning rotor in a subsonic air stream. Development of a new type of model for the magnetic balance system was required in order to provide rotational freedom about all three axes. The design, construction and initial testing of this model at low subsonic speeds are discussed. The results indicate that models with three degrees of rotational freedom can be suspended with the magnetic balance system and tested in a subsonic air stream. Because of the force limits of the present balance system, the maximum operating dynamic pressure for this model is low.

## INTRODUCTION

Magnus forces have long been important to the flight dynamics of specialized munitions. To date, experimental information has been obtained on these configurations by both wind tunnel (1-4) and free flight tests. The wind tunnel tests, of necessity, have utilized stings or yokes of some sort to support the model. These physical model supports have materially interfered with the aerodynamics being studied thus compromising to some extent comparisons between wind tunnel and free drop test. The free drops provided only general performance information because of the nature of the configurations.

This report* describes the design, construction and initial testing of a free spinning Magnus rotor under startup conditions in a magnetic suspension and balance system (5-9). Figure 1 shows the subsonic wind tunnel and magnetic balance system. Figure 2 shows a rotor model magnetically suspended in the opened test section.

## DISCUSSION

### Model Design

The primary objective of this model design is to provide complete angular freedom about three axes while maintaining the maximum possible volume for the iron core. Two possible configurations were consi-

* Some of the material in this report was presented at the AIAA 2nd Atmospheric Flight Mechanics Conference (10).

dered. The first - a precision ball bearing surrounded by small friction pads of teflon or pyrolytic graphite - provided the greatest usable volume of core material. The level of the friction force, however, could not be accurately predicted and it was therefore not developed in favor of the second jewel bearing configuration.

This model configuration consists of five parts shown in Figures 3 - 6. Complete assembly is shown in Figure 7. This model is designed to simulate the dynamics of a free spinning body under startup conditions and to provide force measurements during the steady phase of the motion.

In order to be able to hold the model properly with the magnetic balance and obtain the desired data, all parts of the model should be made of nonmagnetic, non-conducting materials except the magnetic core material that is being held. The outer shell (Fig. 3) is made from a Textolite sleeve with the aerodynamic shape cast onto it with epoxy*. The two end caps (Fig. 4) are machined to shape from cast epoxy. The cage (Fig. 5) is wound from fiber glass filament that is impregnated with epoxy. It is then cast to shape on a Wood's metal mandrel which is later removed by melting. The magnetic core is shown in Figure 6. It is machined from Armco ingot iron. The assembly drawing of the model is shown in Figure 7.

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* Stycast 3050, manufactured by Emerson and Cuming, Inc., Canton, Massachusetts.

This model can be held in the magnetic suspension system and will be free to rotate about three axes. The external aerodynamic shell of the shape shown in Figure 8 is freely pivoted about the gymbal cage with jewel bearings*. This cage is in turn pivoted about the iron core with a second set of jewel bearings (Figure 7). The third degree of rotational freedom is derived from the intrinsic character of the magnetic model which is free to rotate about the principal axis of the magnetic field. This forms the third axis of the gymbal system. As the magnetic core can rotate only about this axis, which remains fixed in space, the combination provides complete freedom of angular motion. Since the position of the core is maintained by the electromagnetic position sensing system (7), all parts of the model except the core must be nonmagnetic, and to the greatest extent possible non-conducting.

In order to obtain angular position and rotational speeds, the model can be painted so that the various positions can be distinguished. To reduce frame-by-frame positions to velocities, accurate timing marks should be superimposed on the film.

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* Each bearing consists of a hard metal tapered pivot which runs against a similarly tapered hole in an aluminum oxide jewel. The jewel is pressed into an adjusting screw. By properly adjusting the relative position of the jewels and pivots, both radial and axial loads can be supported by a single pair of bearings (2 jewels and 2 pivots).

## WIND TUNNEL TESTS

### Initial Wind Tunnel Testing

The subsonic wind tunnel used is described in Reference 11 and Figure 1. The tunnel aerodynamic configuration, however, departed slightly from normal since a 45° mirror was installed in the diffuser of the wind tunnel so that the Magnus rotor could be observed and photographed.

The testing of the model consisted of hanging the model in the suspension system (an operation which requires higher power than most other models) and then simultaneously starting the wind tunnel and exposing the roll of movie film. The camera used was a Fastax Model WF-3 operating at 1,000 frames per second which is the minimum framing rate of this camera. It should be noted that this camera holds 100 foot rolls of film. This means that the maximum observation time with a roll of film is approximately 4.5 seconds.

The model was tested and several rolls of film were taken with the wind velocity at 45 feet per second.

The results of the initial wind tunnel operations indicated that the model was subject to a small torque applied to it by the magnetic field, and this kept the model oriented with its axis parallel to the wind tunnel axis, with the wind off. A check of the model parts showed that the brass jewel holders and the brass jewel screws were very slightly magnetic. This produced a slight torque tending to align the long axis of the rotor with the magnetic field and caused the observed steady precession of the spinning model. To correct this problem some new jewel screws and jewel holders were ordered

in beryllium copper which is nonmagnetic. (The brass was magnetic because of a permitted iron content of up to 1%.)

The brass jewels were ordered first because they were a stock item and it was not known that the brass used had a small iron content.

Force limits on the model.

It should be pointed out that a model of this type is very hard to hold in this present balance system since the system is underpowered. This particular model has a very small magnetic volume compared to its aerodynamic cross section and therefore requires a very strong magnetizing current, in the order of 200 amps., and a high pressure water system to keep the magnetizing windings cool.

## Second Series of Tests

A second series of tests was scheduled to obtain more movies of the Magnus rotor with the new beryllium copper jewel screws and jewel holders. Before the tests the beryllium copper jewel screws and jewel holders were tested in a magnetic field to make sure that they showed no signs of being magnetic. The tests showed that they were indeed nonmagnetic.

In the process of setting up the magnetic balance to hold the model certain irregularities were noticed in the operation of the balance system. The problem was traced to the downstream Helmholtz coil. This coil after examination proved to have a short between two adjacent layers. The two Helmholtz coils provide a uniform magnetizing field for the model. However, with this short in the downstream coil the field was not uniform. To make the fields uniform again, a shorting bar was placed

on the same windings of the upstream coil. After this was done the fields were checked and found to be uniform again. However, further testing on this model, at high power, was suspended for fear of further and more serious damage to the set of coils. It appears that some damage to the high pressure water system in the past partially blocked some tubes in the coil and caused local overheating which resulted in the present damage. Operation with models of larger magnetic volumes can be continued as they require much less magnetizing current to hold the model. However, repair of the magnetic balance by replacing the defective coils will be required before further work on the Magnus rotor can be performed.

Due to the damage to the coil no further films were obtained on the Magnus rotor model.

## CONCLUSIONS

This program demonstrates that testing with the magnetic suspension system is feasible for this model and other unusual aerodynamic shapes, when it is desired to observe their complicated motions under wind tunnel conditions.

In the design of a model of this type, to be used in a magnetic suspension system, it is very important that there be absolutely no magnetic material in the model except for the core. Any magnetic material other than the core provides torques on the aerodynamic shell that distort the true model motion.

A 16 mm, 1,000 frame-per-second motion picture film showing the motion of the rotor was obtained by photographing the model image in a mirror located in the diffuser section of the subsonic wind tunnel.

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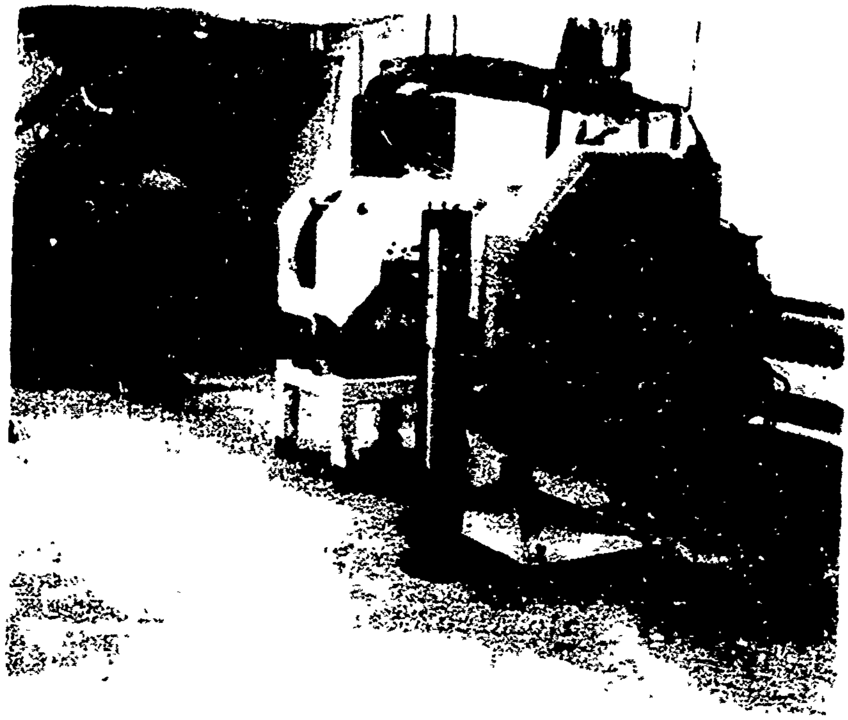

Fig. 1. The Subsonic Tunnel and Magnetic Balance Assembly.

Fig. 2. Rotor Model Magnetically Suspended in Opened Subsonic Test Section.

Note: All Dimensions In Inches.

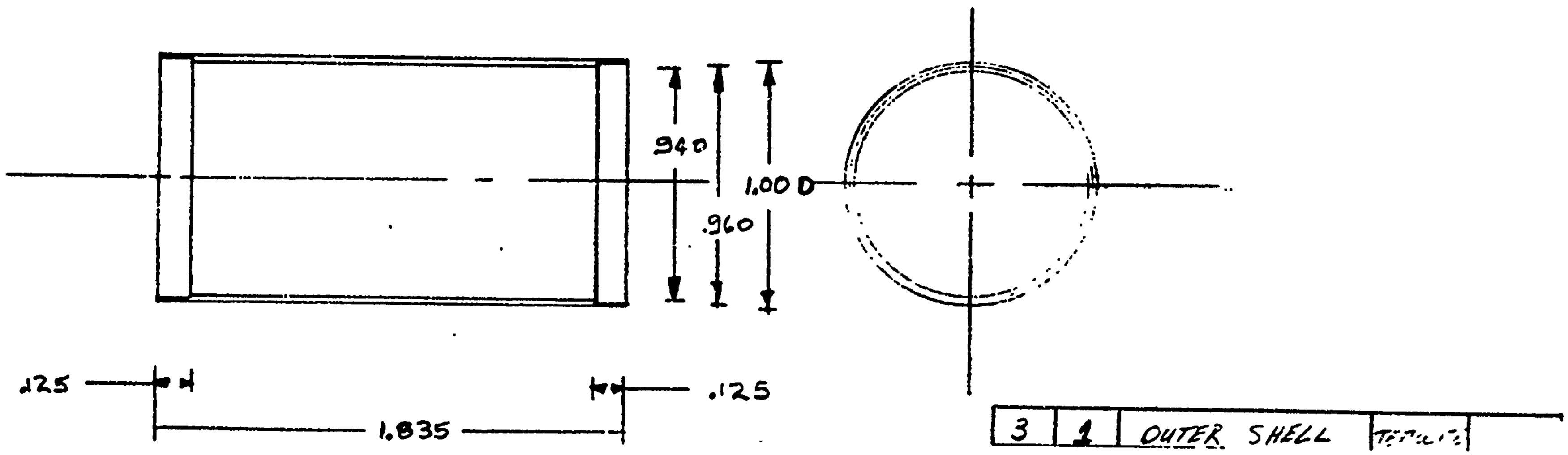


Figure 3. Outer Shell (without vanes)

Note: All Dimensions in Inches.

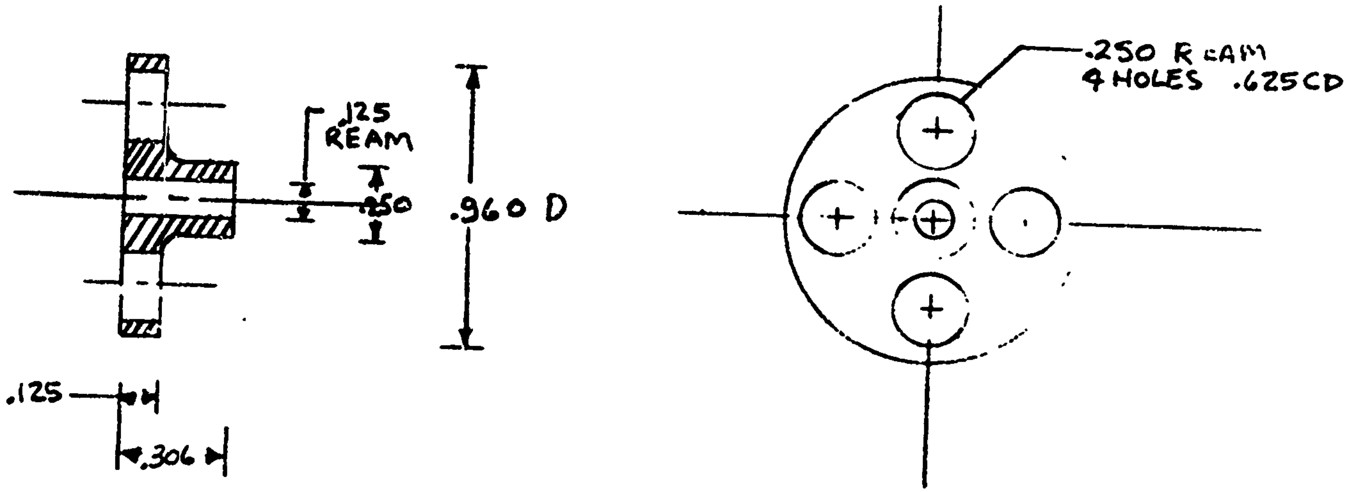


Figure 4. Cast Epoxy End Cap.

| | | |
|---|---|---|
| 2 | 2 | END CAPS |

Note 1. Two holes to be reamed to fit jewel holders.
Note 2. Two holes to be reamed to fit pivots.
Note 3. All Dimensions In Inches.

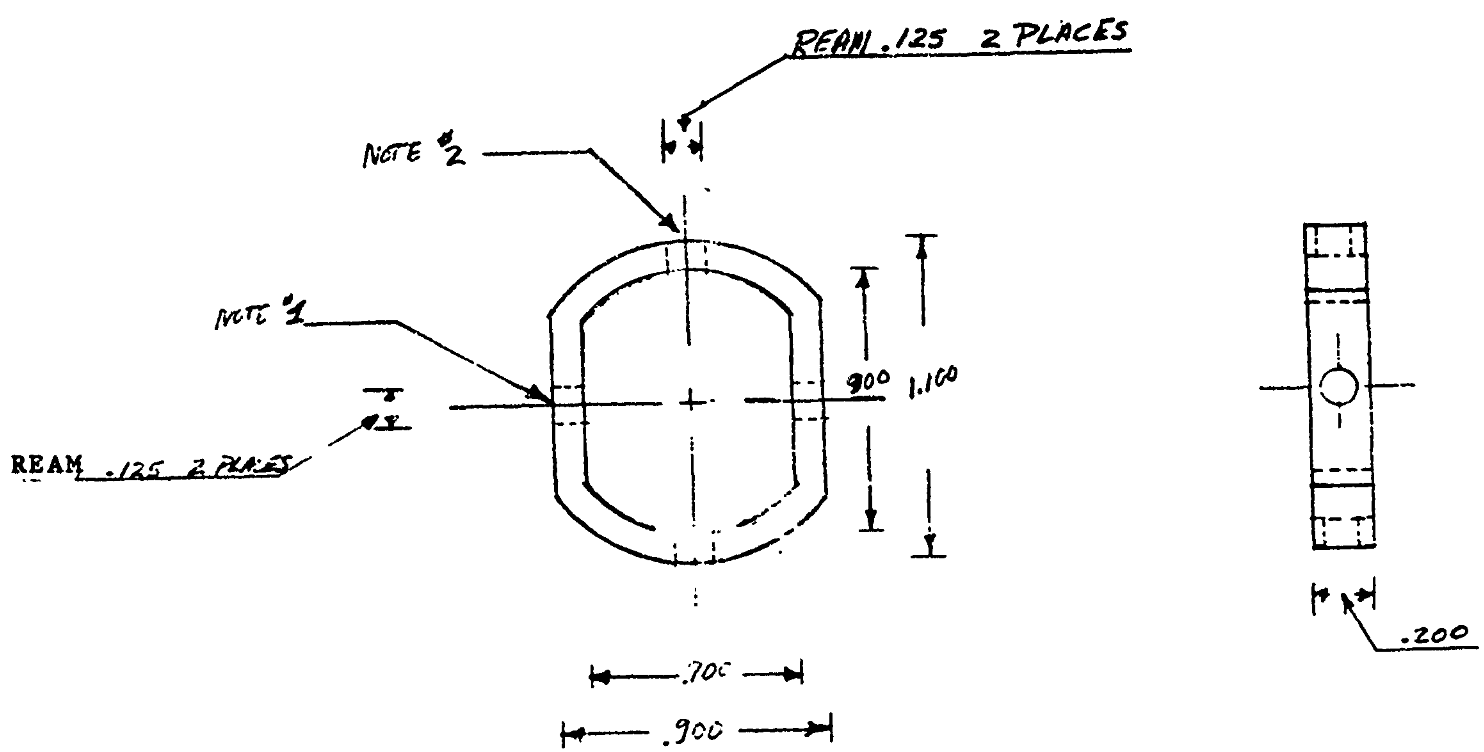


Figure 5. Epoxy-Fiberglass Gymbal Cage.

Note: All Dimensions In Inches.

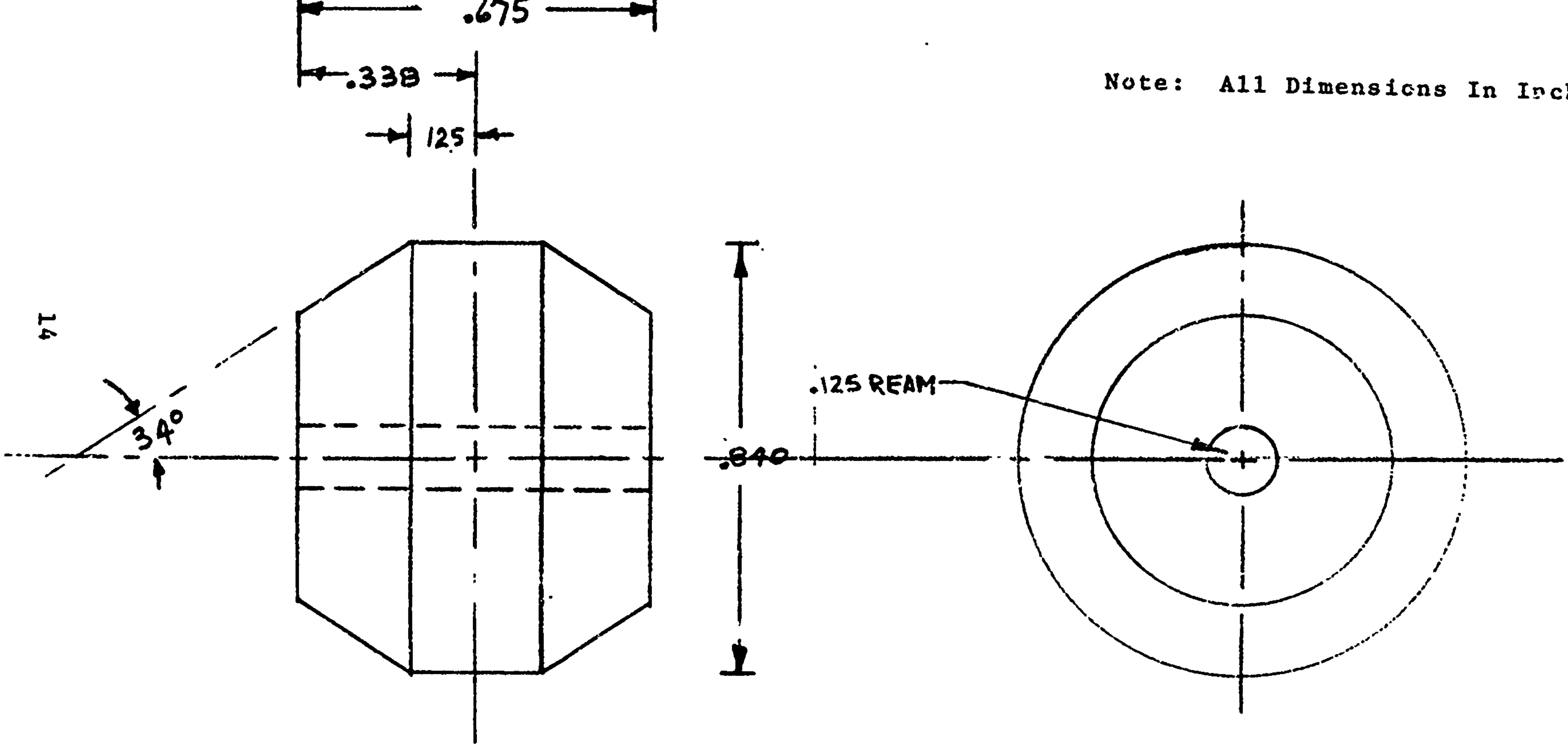


Figure 6. Inner Magnetic Core.

| | | | |
|---|---|---|---|
| 1 | 1 | BODY | [illegible] |

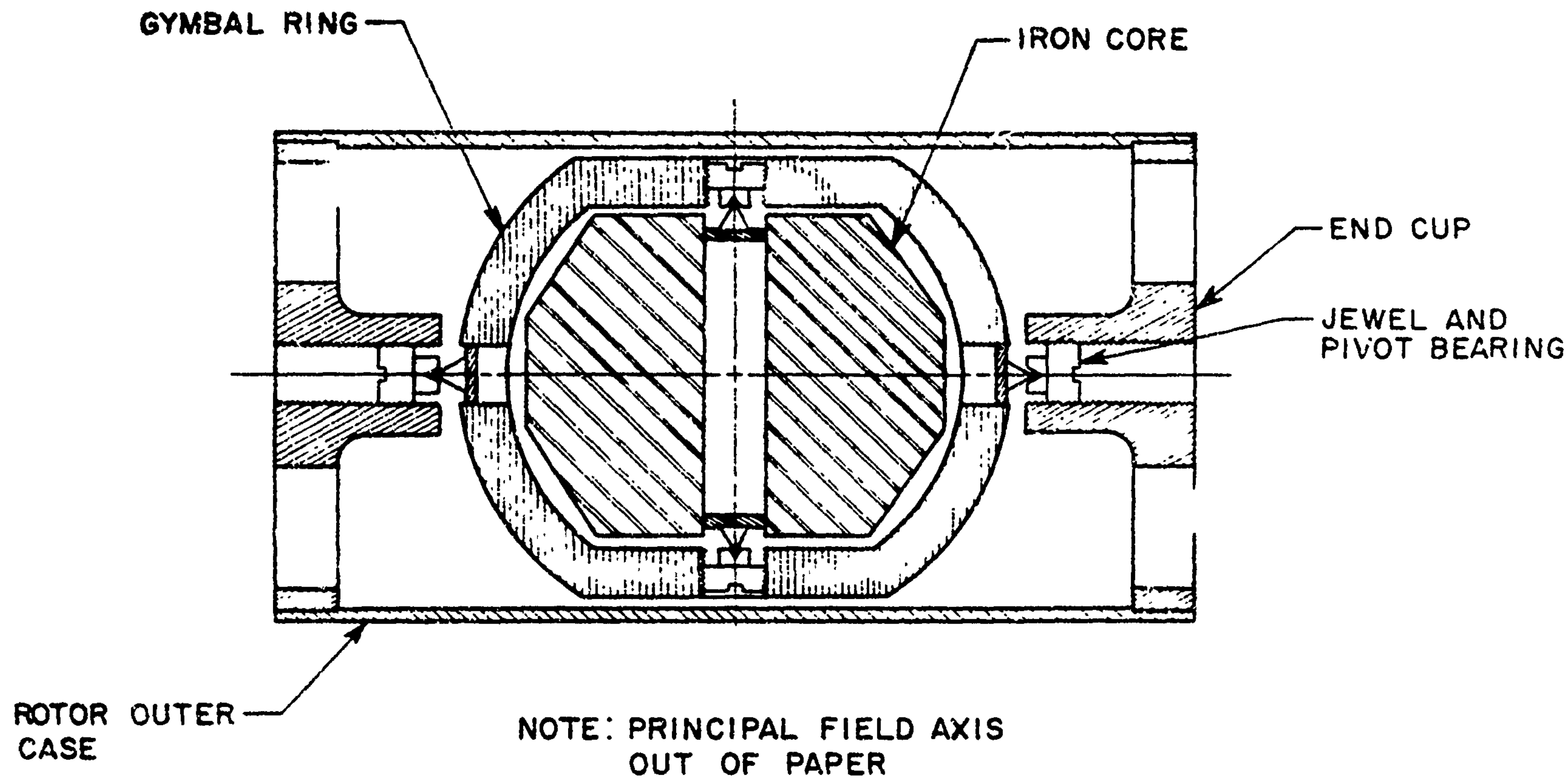


Fig. 7. Free Spinning Magnus Rotor Assembly.

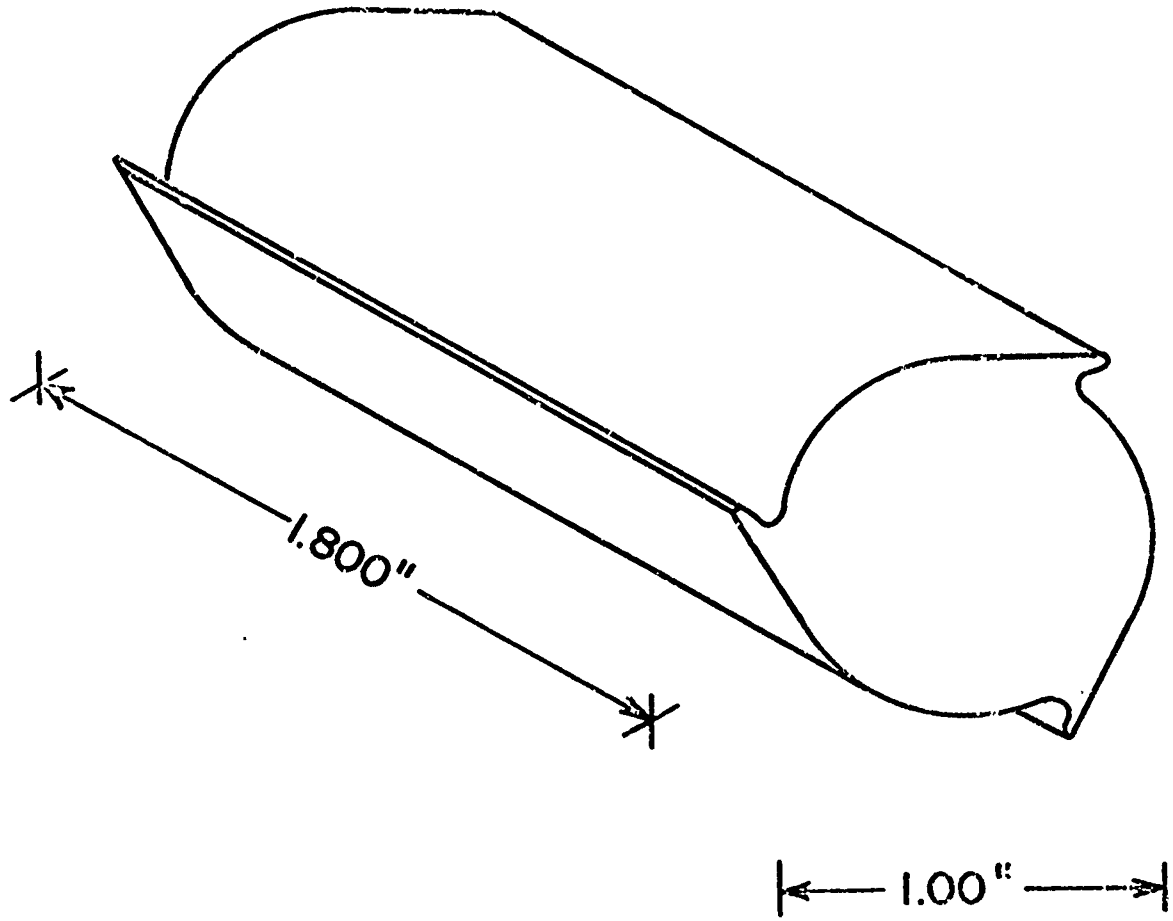


Figure 8. Magnus Model external Geometry.